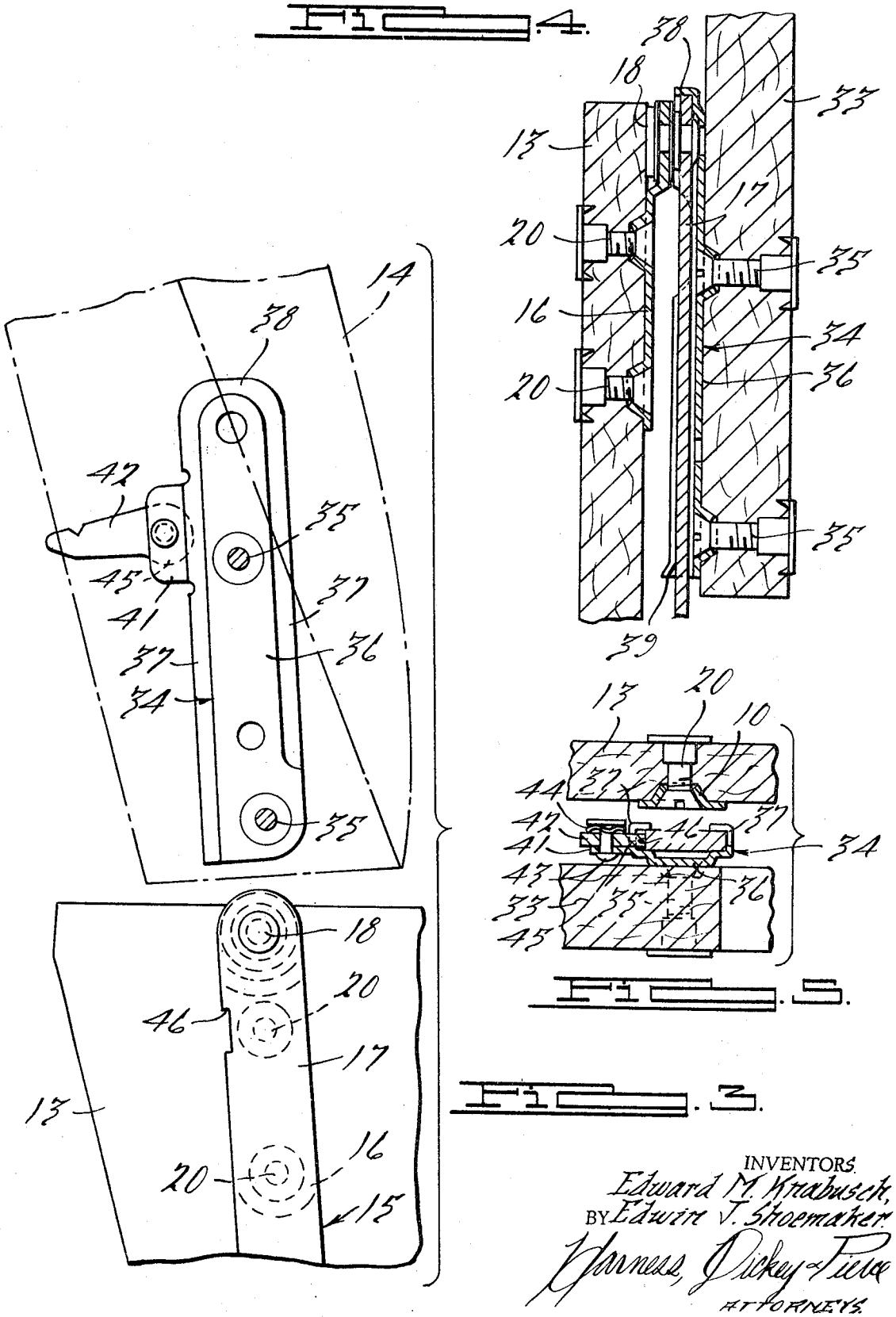
Aug. 25, 1970 E. M. KNABUSCH ET AL 3,525,549

DETACHABLE CHAIR BACK

Filed July 19, 1968 2 Sheets-Sheet 2

FIG. 4.



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APPARATUS AND METHOD FOR PRODUCING SULFUR LOCATED ABOVE A HOT AQUIFER

Filed Feb. 3, 1969 3 Sheets-Sheet 2

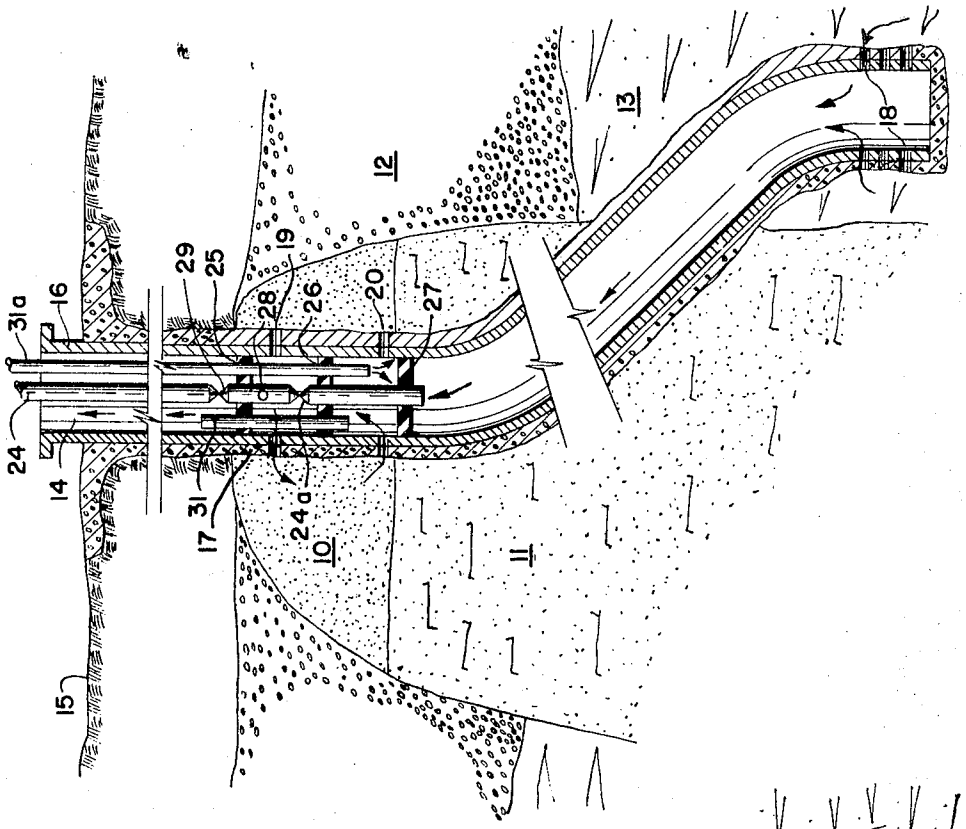


FIG. 3

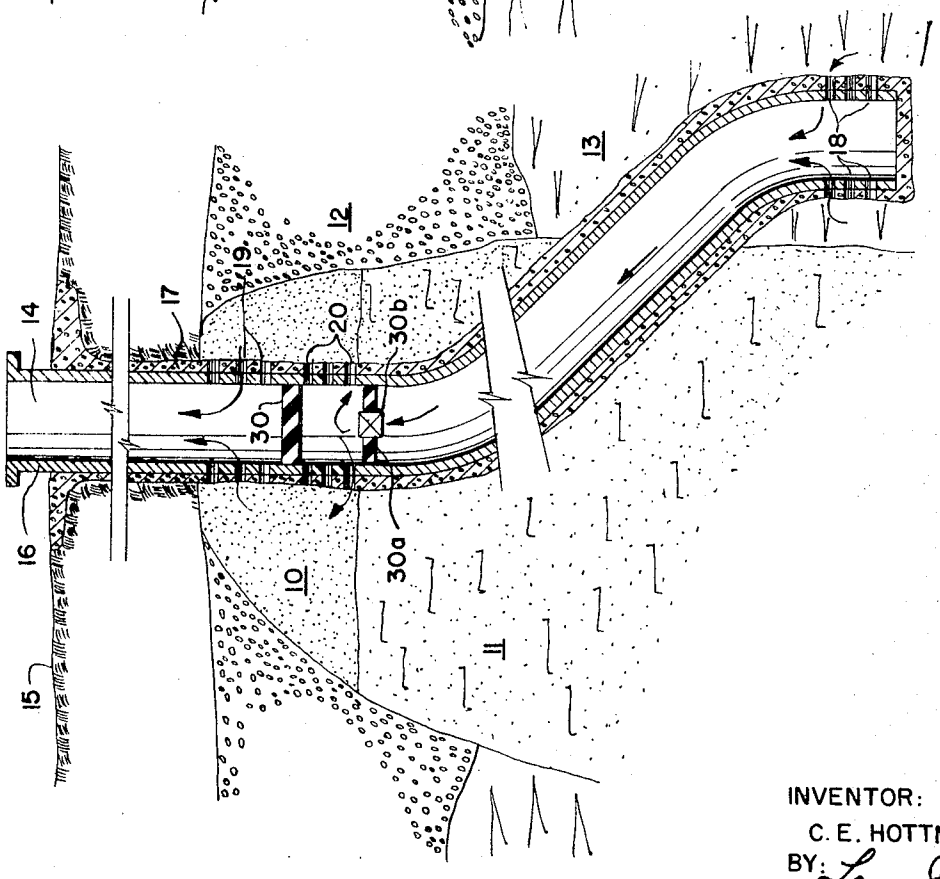


FIG. 4

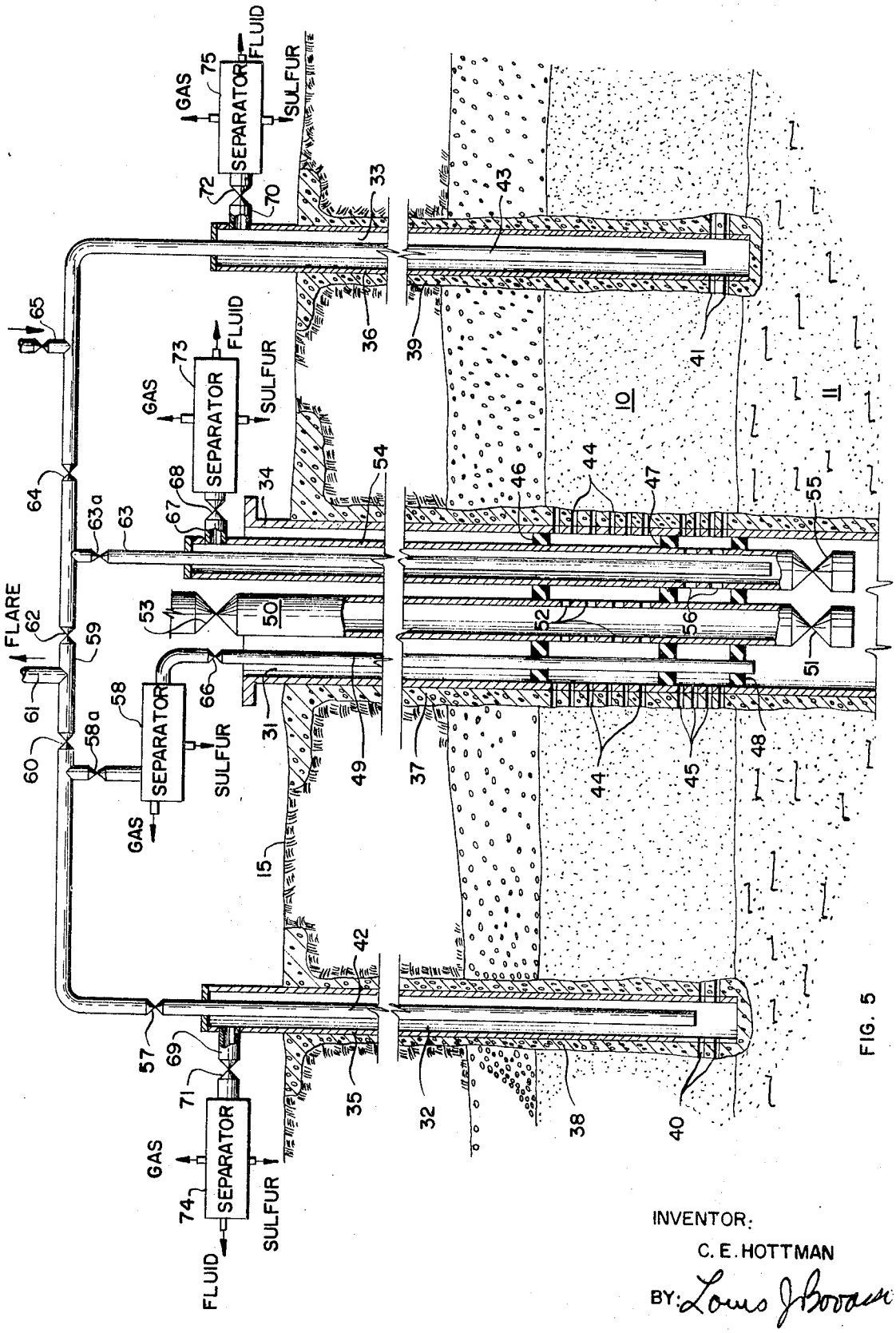
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APPARATUS AND METHOD FOR PRODUCING SULFUR LOCATED ABOVE A HOT AQUIFER

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3 Sheets-Sheet 3



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3,525,550

APPARATUS AND METHOD FOR PRODUCING SULFUR LOCATED ABOVE A HOT AQUIFER

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Int. Cl. E21b 43/28
U.S. Cl. 299—6 15 Claims

ABSTRACT OF THE DISCLOSURE

A method for producing sulfur by locating a subterranean region having a sulfur deposit disposed above and adjacent to a salt dome with a geopressured aquifer disposed below the sulfur deposit and adjacent to the salt dome. Fluid communication is established between a surface location and both the sulfur deposit and the aquifer through at least a portion of the salt dome. A portion of the subterranean pressurized heat existing at the depth of the aquifer is transferred to the sulfur deposit through the salt dome, thereby melting sulfur in contact with the fluid from the aquifer and forcing the melted sulfur to the surface of the ground. Also disclosed is apparatus comprising a tubing extending from the surface and havface location and both the sulfur deposit and the aquifer through at least a portion of the salt dome. A portion of perforated areas located between the upper and lower end and in the sulfur deposit, the areas being separated by packer means to form a system for circulating the hot fluid from the aquifer through the sulfur deposit and to the surface of the earth.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to a method for producing sulfur from subterranean sulfur deposits utilizing heat necessary for melting the sulfur from a geopressured aquifer located deeper than the sulfur deposit.

Description of the prior art

In recovering sulfur from underground formations, one prior art method involves underground fusion wherein a hole or well is drilled to the bottom of a subterranean sulfur deposit through the strata overlying the deposit. This hole is preferably provided with a suitable casing in which a system of concentric pipes is disposed. The sulfur recovery operation is customarily carried out by passing a hot fluid, such as heated water under pressure, down one of the annular spaces formed between the concentric pipes, and into the sulfur-bearing formation. Such fluid is at a temperature such that sulfur is melted and flows in consequence by gravity downwardly to the bottom of the well. The molten sulfur is forced upward through another of the annular spaces a certain distance by the hydrostatic pressure on the formation; then it is picked up in the well piping by a stream of compressed air, and raised to a point where it is discharged above the surface of the ground.

It has also been suggested to recover sulfur by in situ oxidation. However, the burning of sulfur deposits require extra compressor capacity.

When recovering sulfur by underground fusion from

deposits which occur in rock strata over salt domes of the Gulf Coast type, certain difficulties are encountered due to the inherent nature of the geological formation encountered, which result in gradually increasing costs of operation as the mining progresses. The economics of producing sulfur from offshore deposits is presently suffering from the cost of establishing offshore steam-generating, air and/or gas-compressing facilities for conveying steam to offshore locations. The supply of onshore sulfur deposits is diminishing.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a method for producing sulfur from a subterranean sulfur deposit utilizing subterranean heat and pressure energy available at the site of the deposit.

It is a further object of this invention to provide a method for economically producing sulfur, thereby reducing currently excessive costs of externally-generated energy by an amount sufficient to make the economics attractive.

It is a still further object of this invention to provide a method of producing sulfur which does not require any external heating means.

The objects of this invention are attained by locating and utilizing a subterranean region in which a sulfur deposit exists above and adjacent to a salt dome and a geopressured aquifer exists below the sulfur deposit and adjacent to the salt dome. At least one well is drilled into the subterranean region and at least one well conduit is extended through a portion of the salt dome located below the sulfur deposit and opened into fluid communication with the geopressured aquifer. Fluid from the geopressured aquifer, which is relatively hot and high pressured, is flowed from the aquifer, through the intervening portion of the salt dome, and injected into the sulfur deposit. Sulfur is recovered by connecting at least one well conduit between the sulfur deposit and a surface location and utilizing it to recover sulfur that is melted and displaced by the hot fluid that is injected into the deposit.

In a preferred embodiment of the invention, the geopressured aquifer that is utilized is one which contains a significant proportion of gas. The fluid produced from the gas-containing geopressured aquifer is flowed up through the salt dome to at least about the depth of the sulfur deposit and then is separated into substantially independent gaseous and liquid fluids. The separated gaseous fluid is injected into the well conduit through which the molten sulfur is flowed to the surface, to provide a gas-lift effect that facilitates the sulfur recovery, and the separated liquid fluid is injected into the sulfur deposit, to provide heat for melting and sulfur. Gaseous fluid that was so used to facilitate the lifting of the molten sulfur is recovered as a by-product of the sulfur production process.

The temperature of subterranean earth formations increases with increases in the depth below the surface of the earth, usually at rates of about 1° F. per 100 feet of depth. Salt domes are relatively good heat conductors and, since they are often vertically extensive along significant depth intervals, they tend to act as chimneys drawing heat toward the surface of the earth. Geopressured reservoir formations are generally encountered at depths of

at least several thousands of feet below the surface of the earth and geopressured aquifers often contain water at a temperature near or above the 250°–350° F. range that is commonly used in sulfur-mining processes, such as the Frasch process. When fluid is flowed from a geopressure aquifer through an intervening portion of a salt dome and into a sulfur deposit, the heat and pressure of the fluid are increased, or its loss of heat is reduced, by the subterranean heat which has been conducted to that depth interval within the salt dome. The present invention provides a method of utilizing this source of subterranean heat to improve the efficiency of processes such as those described in Pats. 3,258,069 and 3,330,356, relating to locating and utilizing the heat and pressure energy of fluids contained in geopressured aquifers.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a vertical sectional view of a well drilled into both a subterranean sulfur deposit and a geopressured aquifer in accordance with the teachings of this invention;

FIG. 2 is a vertical sectional view of a portion of the well of FIG. 1;

FIG. 3 is a vertical sectional view of a preferred method for carrying out the concepts of this invention; and

FIGS. 4 and 5 are vertical sectional views of alternate methods for carrying out the concepts of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawing, FIG. 1 shows a subterranean sulfur deposit **10** in the form of a sulfur-bearing caprock at the top of a salt dome **11**. Reference numeral **12** indicates normal pressure fluid-bearing sands or reservoirs disposed on the flank of salt dome **11**; reference numeral **13** indicates aqueous fluid-bearing sands or reservoirs disposed on the flank of salt dome **11** below normal pressure sands **12**. The location of such sulfur deposits, salt domes, and geopressured reservoirs may be determined by conventional geophysical means well known in the art. Preferably, such geopressured reservoir waters should have a temperature of approximately 350° F. and a fluid pressure gradient of approximately 0.70 p.s.i. per foot. The temperature and pressure of the fluids in the geopressured sands required to carry out the method of this invention are, to a large extent, governed by the depth of both the sulfur deposit **10** and the geopressured reservoirs **13**. Preferably, such geopressured reservoirs are gas-containing.

After locating the geopressured reservoirs having the desired properties for carrying out the invention, as, for example, reservoirs **13**, at least one energy well is drilled through the sulfur dome and into reservoirs **13**, all of which are in communication. For example, as shown in FIG. 1, a well **14** is drilled through the earth surface **15**, through sulfur deposit **10**, and into communication with geopressured reservoirs **13**. Although only one such well is illustrated in FIG. 1, obviously more than one well may be drilled from earth surface **15** into communication with geopressured reservoirs **13**.

Well **14** is drilled in a conventional manner well known in the art; however, well **14** is preferably drilled through salt dome **11** in such a manner that the greatest portion of the well as possible lies within the salt of the salt dome **11**. Well **14** is then cased at casing **16** and the casing **16** is cemented therein at cementing **17** as is also well known in the art.

The completed cased well **14** is next perforated at perforations **18** at one or more depths opposite the geopressured reservoirs **13**. Well **14** is also perforated at one or more depth intervals, preferably in communication with the upper portion of the sulfur deposit **10** (indicated by perforations **19** in FIG. 1) and at one or more depths opposite the lower portion of sulfur deposit **10** (indicated by perforations **20** in FIG. 1). All such perforations may be made by conventional means well known in the art,

such as by lowering bullet perforating devices into well **14** into the desired position. FIG. 2 illustrates a perforating means whereby a perforating device **21** is lowered by wireline **22** into a desired position in the sulfur deposit **10**. Upon actuation of device **21**, perforations **19** are formed in the well casing **16**, cementing **17** and the surrounding formations. In like manner, one or more perforations **18** and **20** may be formed in well **14**.

In FIG. 3, a fluid flow directive system is shown which may include a tubing string **24** and packers **25**, **26** and **27** disposed, respectively, above, between and below perforations **19** and **20**. An aperture **28** is disposed in tubing string **24** between packers **25** and **26** and in communication with perforations **19**. If desired, the portion of tubing string **24** above packer **25** may be removed, such as by "backing off" the upper portion of the tubing string as is well known in the art. Preferably, however, tubing string **24** may be valve controlled by means of normally-closed valve means **29**. A relatively short section of tubing string, such as tubing string **31**, is disposed in well **14** and extends through packers **25** and **26**, thereby communicating, at its lowermost end, with perforations **20**, and at its topmost end with the annulus formed between tubing string **24** and casing **16** and above packer **25**. Although other fluid flow control or fluid flow directing systems may be used in the arrangement disclosed hereinabove, fluid circulates from geopressured reservoirs **13**, through perforations **18**, up tubing string **24**, out aperture **28** and into sulfur formation **10** through perforations **19**. As indicated by the arrows in FIG. 3, the fluid then circulates down through the sulfur formation **10** and back into the well **14** through perforations **20** and up tubing string **31**. In this manner, a significant portion of sulfur deposit **10** is contacted by the circulating fluid. Gas may be supplied below the lower end of tubing string **31** by injecting gas from an external gas supply (not shown) down tubing string **31***a* so as to gas-lift the fluid circulating out of sulfur deposit **10** to the surface.

Alternatively, as illustrated in FIG. 4, a packer **30** may be installed in well **14** between perforations **19** and **20**. As indicated by the direction of the arrows, fluid flows from geopressured reservoirs **13**, through perforations **19**, up well **14**, through normally open valve **30***b* in packer **30***a*, out perforations **20** and into sulfur deposit **10**. The fluid then circulates through the sulfur deposit **10**, back into well **14** through perforations **19** and out of the well **15**.

In either case, because of the greater fluid pressures in geopressured reservoirs **13**, hot high-pressure fluid flows from reservoirs **13** through perforations **18**, up well **14**, through the respective perforations as indicated and into the sulfur-bearing rock deposit **10**.

This injection of hot water into the sulfur-bearing deposit **10** causes a rise in temperature of deposit **10**. Once the temperature of the deposit **10** is raised above the melting point of sulfur, the solid sulfur present in deposit **10** melts and becomes mobile or liquid. The density of the resultant mixture of fluid and molten sulfur is decreased by reducing the pressure on the fluid from the aquifer, and gas released therefrom or from another source is mixed with the mixture. This may be accomplished, in the case of the embodiment of FIG. 3, by providing conventional pressure control valve means **24***a* in tubing string **24** before aperture **28**. In the case of the embodiment of FIG. 4, packer **30***a* and conventional pressure control valve means **30***b* must be installed below perforations **20**.

As can be seen in both FIGS. 3 and 4, in the step of transferring heat energy from the geopressured reservoirs **13** to the sulfur deposit **10**, the amount of heat that is transferred to the sulfur deposit is supplemented by flowing the fluid released from reservoirs **13** into a heat exchange relationship with the interior of salt dome **11**. This heats or thermally insulates the released fluid by transferring to it or surrounding it by the subterranean heat that

is conveyed preferentially through the salt in the salt dome from a subterranean depth that may be greater than that of the geopressured reservoirs **13**.

A preferred arrangement for producing sulfur from a subterranean deposit in accordance with the teachings of this invention is illustrated in FIG. 5. A sulfur-bearing zone is indicated in sulfur deposit **10**. An energy well **31** is shown extending into the sulfur-bearing zone. The well **31** continues down through the sulfur-bearing zone, through salt dome **11** and into the geopressured formation or formations (not shown in FIG. 5) in the manner discussed hereinabove with respect to FIGS. 1 through 4.

Well **31** is preferably surrounded by at least a pair of spaced producing wells **32** and **33**. Wells **32** and **33** preferably terminate at the bottom of the sulfur-bearing zone. All the wells **31** through **33** are preferably cased (as at casings **34** through **36**, respectively) with the casings cemented therein (as at cementings **37** through **39**, respectively). Thus, wells **32** and **33** are preferably cemented below the base of the sulfur-bearing zone.

Wells **32** and **33** include perforations **40** and **41**, respectively, preferably at their lower ends in communication with the bottom portion of the sulfur-bearing zone. Wells **32** and **33** also include tubing strings **42** and **43**, respectively, extending through the appropriate well and into position adjacent their respective perforations.

Referring now to energy well **31**, casing **34** is preferably a large-diameter casing perforated both at perforations **44** in the upper part of the sulfur-bearing zone and at perforations **45** in the lower part of the sulfur-bearing zone. Perforations **44** and **45** are packed off from one another by installing packers **46**, **47** and **48** above perforations **44**, between perforations **44** and **45** and below perforations **45**, respectively. A gas tubing string **49** is installed in well **31** below packer **48** as illustrated in FIG. 5. A slotted liner **50** having downhole valve means **51** at its lower end is set in well **31** through packers **46**, **47** and **48** in such a manner that its apertures, as for example slots **52**, are disposed in the portion of well **31** between packers **46** and **47** opposite perforations **44** and valve means **51** is disposed below packer **48**. The upper end of liner **50**, extending out of well **31**, is preferably controlled by valve means **53**.

A second slotted liner **54** having downhole valve means **55** at its lower end is also set in well **31** through packers **46**, **47** and **48** in such a manner that its apertures, as for example slots **56**, are disposed in the portion of the well **31** between packers **47** and **48** opposite perforations **45** and valve means **55** is disposed below packer **48**.

A suitable control valve means **57** is disposed at the upper end of tubing string **42** of producing well **32**. Tubing string **42** passes into a conventional separator **58** and through a branch portion **59** controlled by conventional valve means **60** where undesirable gases may be flared off at **61**. Branch portion **59** passes through second control valve means **62** and meets a tubing string **63** disposed in liner **54** in energy well **31**. Tubing string **63** extends down through and is concentric with liner **54**. Tubing string **63** is imperforate and open at its bottom, which terminates below packer **48** and above valve means **55**.

At its junction with tubing string **63**, branch portion **59** also passes through control valve means **64** and either forms, or comes into contact with, tubing string **43** of producing well **33**. An external gas supply line **65**, controlled by valve means **66**, is preferably disposed between valve means **64** and tubing string **43**.

Tubing string **49** of energy well **31** also passes into separator **58** and is controlled by valve means **66**. Liquid sulfur may be withdrawn from liner **54** through a suitable sulfur outlet **67**, controlled by valve means **68**. Sulfur and gas may be withdrawn from producing wells **32** and **33** through gas and sulfur outlets **69** and **70**, respectively, controlled by valve means **71** and **72**, respectively. From outlets **67**, **69** and **70**, the withdrawn mixtures are passed into suitable separators **73** through **75** respectively, where the mixtures are separated into sulfur, fluid and gas.

In operation, the following method for producing sulfur from sulfur-bearing zone may be employed.

Valve means **51** of liner **50** is opened and valve means **53** is closed. Hot fluid flows from the geopressured reservoirs **13** (FIGS. 1, 3 and 4), in the manner discussed hereinabove, up well **31** through salt dome **11** and into the portion of casing **34** below packer **48**. Fluid flows into liner **50** through valve means **51** and out through the slots **52** into the annular space between packers **46** and **47**. The hot fluid then flows through perforations **44** into the sulfur-bearing zone. The fluids continue to flow from geopressured reservoirs **13** (FIG. 3) into the sulfur-bearing zone continually heating the solid sulfur until it melts and becomes a liquid. Since the density of liquid sulfur is approximately twice that of water, the liquid sulfur flows to the base of the sulfur-bearing zone. As more and more liquid sulfur accumulates at this base, liquid sulfur enters perforations **45** of the energy well **31** and the perforations **40** and **41**, of production wells **32** and **33**, respectively.

At this point, gas, essentially methane, is injected down tubing strings **42** and **43** of the production wells **32** and **33** through external gas supply line **65** and the liquid sulfur is "gas-lifted" up the annulus space between casings **35** and **36** of production wells **32** and **33** and out of outlets **70** and **69**, respectively. Although two such production wells are illustrated in FIG. 5, obviously one or more production wells may be used such as several similar production wells simultaneously producing liquid sulfur.

Gas-lifting operations may also be carried out in energy well **31** simultaneously with fluid displacement from the energy well **31** into the sulfur-bearing zone. The liquid sulfur entering casing **34** through perforations **45** passes through slots **56** and into liner **54**. Gas may then be injected down tubing string **63** into liner **54** and liquid sulfur is gas-lifted up the annular space of liner **54** and out of outlet **67**. In the foregoing steps, it is assumed that the suitable valve means are opened or closed, as desired. A valve **63***a* may be disposed at the top of tubing string **63** so that string **63** may be by-passed when injecting gas into well **32**. Also, a control valve **58***a* may be disposed at the top of separator **58** so as to bypass the separator **58**, if desired.

Alternatively to the method discussed hereinabove, valve means **55** of liner **54** may be opened and hot water injected into the lower portion of the sulfur-bearing zone when it contains liquid sulfur. Thus, hot water from the geopressured reservoirs **13** passes through valve means **55**, out slots **56** and through perforations **45** into the lower portion of the sulfur-bearing zone. This hot injected fluid displaces the liquid sulfur through perforations **40** and **41** into production wells **32** and **33**, respectively. In this manner, gas lift may not be necessary with the sulfur and gas created by the mixture of the hot fluid and liquid sulfur produced out of wells **32** and **33** through outlets **70** and **69**, respectively. In this feature of the invention, it may be necessary to close valve means **51** and **53** of liner **50**. This feature of the invention may be alternated with the foregoing steps to produce sulfur.

As a preferred feature of this invention, the hot, highly-pressurized fluids contained in many geopressured aquifers are saturated with or contain dissolved hydrocarbon compounds such as methane. Upon producing such fluids, the pressure and temperature is reduced and these dissolved hydrocarbons come out of solution, and the fluids separate into a mixture of a gaseous fluid and a liquid fluid.

The gaseous fluid may be utilized in the gas lift portion of the present invention. Accordingly, much of the dissolved gas is separated in the annular space of casing **34** below packer **48** and above the bottom of liners **50** and **54**. This separated gas (containing water) is produced up tubing string **49** and into separator **58**. The pressure

of separator 58 is preferably maintained at a sufficient pressure such that no additional energy is required to inject the gas into the tubing strings 42 and 43 of producing wells 32 and 33, respectively and/or the tubing string 63 of energy well 31 as disclosed in the foregoing steps.

I claim as my invention:

1. In a method of producing sulfur comprising:
- locating a subterranean region having a sulfur deposit disposed above and adjacent to a salt dome with with a geopressured aquifer disposed below the sulfur deposit and adjacent to the salt dome;
- establishing fluid communication between a surface location and both said sulfur deposit and said aquifer through at least a portion of said salt dome;
- transferring a portion of the subterranean pressurized heat existing at the depth of the aquifer to the sulfur deposit by flowing the pressurized fluid in the aquifer from the aquifer through said portion of said salt dome into the sulfur deposit thereby melting sulfur in contact with the fluid from the aquifer; and
- flowing the mixture of fluid and molten sulfur from the sulfur deposit to said surface location.

2. The method of claim 1 including the step of recovering sulfur from the mixture of fluid and molten sulfur flowing to said surface location.

3. The method of claim 1 including the step of locating said subterranean region adjacent to a gas-containing geopressured aquifer and separating the fluid produced from said aquifer into substantially independent gaseous and liquid fluids; and
- flowing said separated gaseous fluids to said surface location, thereby providing a gas-lift to said molten sulfur while injecting the separated liquid fluid into said sulfur deposit thereby providing heat for melting said sulfur.

4. The method of claim 3 including the step of recovering said gaseous fluid as a by-product.

5. Apparatus for producing sulfur from a subterranean sulfur deposit located at the top of a salt dome and a gas-containing geopressured aquifer that is located deeper than the sulfur deposit but higher than the bottom of the salt dome, said apparatus comprising:
- at least one well extending from a surface location through both said sulfur deposit and said salt dome and into said aquifer;
- a well casing permanently fixed in said well;
- first perforations extending through said well casing and into said aquifer;
- second perforations extending through said well casing and into the upper portion of said sulfur deposit;
- third perforations extending through said well casing and into the lower portion of said sulfur deposit; and
- packer means disposed in said well below the second perforations and above the third perforations for sealing said second perforations from said third perforations.

6. The apparatus of claim 5 wherein the greater portion of said well extends through said salt dome.

7. The apparatus of claim 5 including packer means having a pressure control valve therein disposed below said third perforations and above said first perforations.

8. The apparatus of claim 5 including second and third packer means disposed both above said second perforations and below said third perforations, respectively, for sealing said perforations;
- a first tubing string disposed in said well and extending through all of said packer means;
- aperture means disposed in said tubing string between said first and second packer means thereby communicating said aperture means with said second perforations; and
- a second tubing string extending through said first and second packer means having its lower end in communication with said third perforations.

9. The apparatus of claim 8 including valve control means disposed in said first tubing string below said aperture means for controlling flow through said tubing string.

10. The apparatus of claim 5 including at least one cased producing well spaced from said first mentioned well, said producing well extending to at least the bottom of said sulfur deposit and having perforations communicating said producing well with said sulfur deposit;
- packer means disposed in said first-mentioned well both above and below said second and third perforations, respectively, for sealing said perforations;
- a first tubing string disposed in said first-mentioned well and extending through all of said packer means in said first-mentioned well so that the lower end of said first tubing string is disposed below said third packer means;
- aperture means disposed in said first tubing string between said first and second packer means thereby communicating said aperture means with said second perforations;
- valve means disposed at both the upper and lower ends of said first tubing string for selectively opening and closing the upper and lower ends of said first tubing string;
- a second tubing string disposed in said first-mentioned well and extending through all of said packer means in said first-mentioned well so that the lower end of said second tubing string is disposed below said third packer means;
- aperture means disposed in said second tubing string between said first and third packer means thereby communicating said aperture means in said second tubing string with said third perforations; and
- normally closed valve control means disposed at the lower end of said second tubing string for controlling fluid flow therethrough.

11. The apparatus of claim 10 including:
- a tubing string disposed in said producing well opening below said perforations in said producing well; and
- external gas supply means coupled to said last-mentioned tubing string for supplying gas thereto.

12. The apparatus of claim 11 wherein at least two cased, producing wells are spaced from said first-mentioned well;
- each of said producing wells having perforations substantially adjacent to the bottom of said sulfur deposit, tubing strings disposed therein extending below said perforations in said producing wells and external gas supply means coupled to each of said producing well tubing strings for supplying gas thereto.

13. The apparatus of claim 11 including gas outlet means disposed in said first-mentioned well, said gas outlet means extending through all of said packer means and opening below said third packer means;
- said gas outlet means being adapted to remove gases dissolved in said aquifer;
- gas separator means coupled to said gas outlet means for separating gas from said gases dissolved in said aquifer; and
- coupling means for coupling said gas separator to said external gas supply means for providing the gas supplied to said tubing string disposed in said producing well.

14. The apparatus of claim 10 including a third tubing string disposed in said first-mentioned well and extending through said second tubing string below said aperture means therein so that the lower end of said third tubing string is in communication with the aperture means in said second tubing string; and
- external gas supply means coupled to said third tubing string for supplying gas thereto.

15. The apparatus of claim 14 including gas outlet means disposed in said first-mentioned well, said gas outlet means extending through all of said packer means and opening below said third packer means;

said gas outlet means being adapted to remove gases dissolved in said aquifer;

gas separator means coupled to said gas outlet means for separating gas from said gases dissolved in said aquifer; and

coupling means for coupling said gas separator means

to said external gas supply means for providing the gas supplied to both tubing string disposed in said producing well and said third tubing string disposed in said first-mentioned well.

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ERNEST R. PURSER, Primary Examiner